

Big data: architectures and data analytics

Hadoop Internals

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Based on the slides of prof. Pietro Michiardi "Hadoop Internals"
<https://github.com/michiardi/DISC-CLOUD-COURSE/raw/master/hadoop/hadoop.pdf>

Terminology - Recap

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- Job: execution of a MapReduce application across a data set
- Task: execution of a Mapper or a Reducer on a split of data
- Task Attempt: attempt to execute a task

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Terminology - Recap

- For instance, consider running "Word Count" across 20 splits
 - 1 job
 - 20 map tasks (on for each input split)
 - A user specified number of reduce tasks
 - At least 20 mapper tasks + number of reducers tasks attempts will be performed
 - More if a machine crashes

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Terminology - Recap

- Task Attempts
 - Each task is attempted at least a maximum number of times (the maximum number of attempts per task is a parameter of the cluster configuration)
 - If there is a temporary fault, the execution of each task may initially fail but it succeeds in the following attempts

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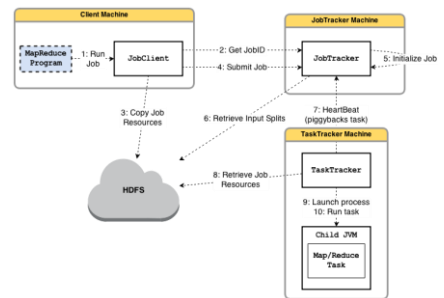
Terminology - Recap

- Multiple attempts may occur in parallel (a.k.a. speculative execution)
 - If there is enough available resources (i.e., there are processors in the idle state and enough main memory to run new tasks) Hadoop can duplicate a task and execute each "copy" of the task in a different node of the cluster (containing the input split)
 - Useful if one node has some problems during the execution of the task
 - The maximum number of duplicates per task is equal to the number of replicas of the HDFS file system

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Anatomy of a MapReduce Job Run

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Job Submission

- JobClient class
 - The "submission" of the job in the Driver creates a new instance of a JobClient
 - Then it calls the `submitJob()` on this class
- Initial verifications before submitting the Job
 - Is there an output directory?
 - Are there any input splits?
 - Can I copy the JAR of the job to HDFS?
 - i.e., Can I copy/move code to data?

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Job Initialization

- The JobTracker
 - Creates an object for the job
 - Encapsulating its tasks
 - Manages tasks' status
- This is where the scheduling happens
 - JobTracker performs scheduling by maintaining a queue
 - Queuing disciplines are pluggable

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Job Initialization

- Compute mappers and reducers
 - JobTracker retrieves input splits
 - Computed by JobClient
 - Determines the number of Mappers based on the number of input splits
 - Reads the configuration information to set the number of Reducers

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Scheduling

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Task Assignment

- Heartbeat-based mechanism
 - TaskTrackers periodically send heartbeats to the JobTracker
 - It means "TaskTracker is alive"
 - Heartbeat contains also information on availability of the TaskTrackers to execute a task

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Task Assignment

- Selecting a task
 - JobTracker first needs to select a job (i.e., Job scheduling)
 - TaskTrackers have a fixed number of slots for map and reduce tasks
 - JobTracker gives priority to map tasks
- Data locality
 - JobTracker is topology aware (i.e., knows the structure of the hardware and the location of the HDFS blocks containing the data of interest)
 - Useful for map tasks
 - Unused for reduce tasks

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Task Execution

- Now TaskTrackers can
 - Copy the JAR from HDFS
 - Create a local working directory
 - Create an instance of TaskRunner
- TaskRunner launches a child java virtual machine (JVM)
 - This prevents bugs from stalling the TaskTracker
 - A new child JVM is created for each input split

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Scheduling in detail

- FIFO Scheduler (default in vanilla Hadoop)
 - First-come-first-served
 - Long jobs monopolize the cluster
- Fair Scheduler (default in Cloudera)
 - Every user gets a fair share of the cluster capacity over time
 - Jobs are placed into pools, one for each user
 - Users that submit more jobs have no more resources than others
 - Can guarantee minimum capacity per pool

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Failures

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Handling Failures

- Processes can crash and machines can fail
- Task Failure
 - Case 1: map or reduce task throws a runtime exception
 - The child JVM reports back to the parent TaskTracker
 - TaskTracker logs the error and marks the TaskAttempt as failed

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Handling Failures

- Case 2: Hanging tasks
 - TaskTracker notices no progress updates (timeout = 10 minutes)
 - TaskTracker kills the child JVM
- JobTracker is notified of a failed task
 - Avoid rescheduling the task on the same TaskTracker
 - If a task fails more than maximum times, it is not re-scheduled
 - If any task fails maximum times, the job fails

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Handling Failures

- TaskTracker Failure
 - Types
 - Crash
 - Running very slowly
 - Heartbeats will not be sent to JobTracker
 - JobTracker waits for a timeout (10 minutes), then it removes the TaskTracker from its scheduling pool
 - JobTracker
 - needs to reschedule even completed tasks
 - needs to reschedule tasks in progress
 - may even blacklist a TaskTracker if too many tasks failed

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Handling Failures

- JobTracker Failure
 - Currently, Hadoop has no mechanism for this kind of failure
 - In future (and commercial) releases
 - Multiple JobTrackers
 - Use ZooKeeper as a coordination mechanisms
 - High Availability

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Internals

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Shuffle and Sort

- The MapReduce framework guarantees the input to every reducer to be sorted by key
 - The process by which the system sorts and transfers map outputs to reducers is known as shuffle
- Shuffle is the most important part of the framework
 - Good understanding allows optimizing both the framework and the execution time of MapReduce jobs
 - Subject to continuous refinements

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Shuffle and Sort: Map Side

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Shuffle and Sort: the Map Side

- The output of a map task is not simply written to disk
 - In memory buffering
 - Pre-sorting
- Circular memory buffer
 - 100 MB by default
 - Threshold based mechanism to spill buffer content to disk
 - Map output written to the buffer while spilling to disk
 - If buffer fills up while spilling, the map task is blocked

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Shuffle and Sort: the Map Side

- Disk spills
 - Written in round-robin to a local dir
 - Output data is partitioned corresponding to the reducers they will be sent to
 - Within each partition, data is sorted (in-memory)
 - Optionally, if there is a combiner, it is executed just after the sort phase

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Shuffle and Sort: the Map Side

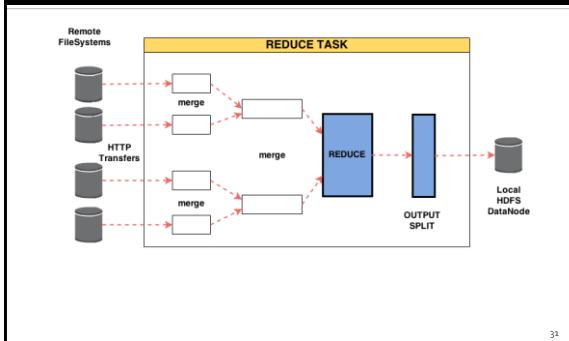
- More on spills and memory buffer
 - Each time the buffer is full, a new spill is created
 - Once the map task finishes, there are many spills
 - Such spills are merged into a single partitioned and sorted output file

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Details on local spill files

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Shuffle and Sort: Reduce Side



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Shuffle and Sort: the Reduce Side

- The map output file is located on the local disk of TaskTracker
- Another TaskTracker (in charge of a reduce task) requires input from many other TaskTracker (that finished their map tasks)
- How do reducers know which TaskTrackers to fetch map output from?
 - When a map task finishes it notifies the parent TaskTracker
 - The TaskTracker notifies (with the heartbeat mechanism) the JobTracker
 - A thread in the reducer polls periodically the JobTracker
- TaskTrackers do not delete local map output as soon as a reduce task has fetched them

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Shuffle and Sort: the Reduce Side

- The map output are copied to the TraskTracker running the reducer in memory (if they fit)
 - Otherwise they are copied to disk
- Input consolidation
 - A background thread merges all partial inputs into larger, sorted files
- Sorting the input
 - When all map outputs have been copied a merge phase starts
 - All map outputs are sorted maintaining their sort ordering

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